TRAVERSING-SLOT RUNOFF SAMPLER FOR SMALL WATERSHEDS

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SUMMARY

A traversing-slot sampler was constructed to sample runoff from small watersheds. The traversing slot moves back and forth through the flow nappe from a modified Parshall flume, extracting a portion of the flow during each traverse. In laboratory tests, the sampling rate (proportion of total flow extracted) decreased as discharge through the flume increased. Because of the decreasing sampling rate, the sampler is not an acceptable flow-measuring device. It does provide a representative sample for determining the sediment concentration of runoff. Assuming the sampler to extract equal proportions of water and sediment, the computed error in sediment concentration of the sample did not exceed 5 percent for a selected group of storms representing a wide range of runoff conditions.

For field tests the sampler was mounted on a 2-foot Parshall flume on a 1.6-acre watershed. Mechanically, it has performed satisfactorily with virtually no downtime. Sufficient field data are not yet available to evaluate the accuracy of the sampler for determining sediment concentration under field conditions.

Automatic samplers capable of sampling the entire flow cross section from watersheds ranging in size from a few acres to 50 or 100 acres have not yet been perfected. Even though there is great need for data from such areas in studies of sediment yield, sediment delivery ratios, and washoff of agricultural chemicals, little work has been done on the development of sampling equipment. This report describes initial attempts to develop a sampler for this purpose.

INTRODUCTION

Runoff samplers have been used extensively in studies of soil erosion from small drainage areas. Sampling devices such as the Geib multislot divisor and the Coshocton-type wheel runoff sampler

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have performed well under field conditions when properly installe and maintained (*1, 2, 4, 6, 7, 10*).[3] However, primarily because o their limited capacity, use of these samplers has usually been re stricted to drainage areas of less than 1 acre.

Hand-operated, depth-integrating, suspended-sediment sam plers have also been developed for sampling runoff (streamflow) from large drainage areas (*8*). Automatic suspended-sediment sam plers developed in recent years have thus far been designed to pro vide a sample from a single point only in the flow cross section (*3 9*).

SAMPLER OPERATION

The traversing-slot sampler is designed to extract a representative sample of the total flow cross section. Specifically, it samples at regular intervals throughout the period of storm runoff. Its purpose is to extract a sample for determining the mean sediment or chemical concentration of runoff, not the volume of runoff.

The sampler operates simply, with minimum maintenance requirements. It is constructed from readily available materials and components. It can be fabricated in an ordinary machine shop by a good machinist.

The sampler operates in conjunction with a 1-, 2-, or 3-foot Parshall runoff measuring flume (fig. 1). The flume was modified by removing the head recovery section to provide a free overfall; the sampler was mounted on the downstream end of the flume throat section (*5*).

The sampler, fabricated from aluminum plate, is roughly rectangular. It is approximately 3 feet high, 1.5 feet deep, and 3 inches thick. The front, or upstream, edge is tapered and beveled from the 3-inch thickness to a 3/16-inch slot opening.

Chain-driven by a ¼-horsepower direct-current electric motor, powered by two 12-volt automotive batteries, the sampler traverses back and forth through the flow nappe with a pause period on each side of the flume. Sampler travel speed is about 10 feet per minute. Power requirements are small since the sampler is mounted on sealed ball bearings, which act as casters. Studs, ½-inch in diameter by 1-inch long, mounted on the drive chain slip into and out of sockets to drive the sampler from side to side.

The sample, extracted through the slot on the upstream edge of the sampler, is routed through the outlet spout at the bottom to a storage tank beneath the flume. A sample splitter installed on the top of the tank further reduces the volume of sample retained.

The sampler is activated automatically when runoff begins by

[3] Italicized numbers in parentheses refer to items in "Literature Cited," p. 14.

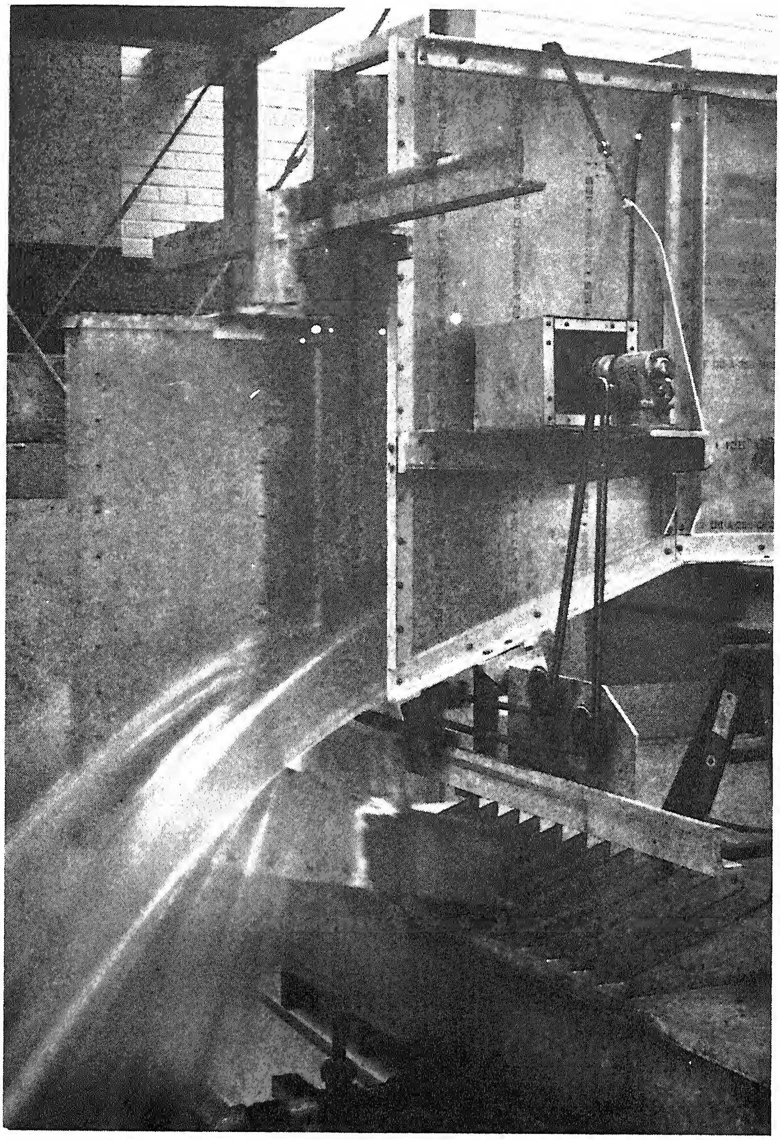


FIGURE 1.—Traversing-slot sampler mounted on a 1-foot Parshall flume. The sample extracted from the flow is directed onto a splitter that further reduces the volume. The sample is stored in the tank under the splitter.

a float switch in the flume recorder well. Operation ceases when the water level recedes to the point where runoff stops. The sampler will operate for several hours on fully charged batteries. Where electric power is available, a trickle charger will keep the batteries fully charged, even when the sampler is operating, and the batteries

will be a source of reserve power during periods of electric power failure.

SAMPLING RATE

The principle of the sampler is described by the following equations:

Assuming no head loss through the slot as it passes through the flow jet (fig. 2), the flow rate into the slot (q_s) is

$$q_s = W_s y v,$$

where W_s=slot width,
y=depth of jet flow,
and v=velocity of jet flow.

The volume (Q_s) extracted in one complete traverse of the sampler is

$$Q_s = W_s y v (T_1/T_2) T_2$$

where T_1=time sampler is in jet per traverse of sampler,
and T_2=time of one complete traverse.

The mean flow rate into the slot per unit time (q_s) is

$$q_s = q_j (W_s/x) (T_1 T_2),$$

where q_j=jet flow rate,
and x=width of jet or width of flume.

The ratio of the flow into the sampler slot to the flow of the jet (r) is

$$r = (W_s/x) (T_1/T_2),$$

and the sampling rate (SR) in percent of jet flow is

$$SR = q_j r (100).$$

Since the drive chain travels continuously at a constant speed and since the sampler is propelled from a fixed point on the chain, the ratio of twice the width of the flume to the total length of drive chain can be substituted for the term T_1/T_2 in the foregoing equations.

$$T_1/T_2 = \frac{2\,(\text{width of flume})}{\text{chain length}}$$

This eliminates the necessity of timing the travel speed of the sampler.

Obviously, the sampling rate is not as precise as the equations indicate, for several reasons: (1) Some head loss occurs as the fluid flows through the sampler slot, and this varies with the jet velocity. (2) The effective width of the slot is greater than the width of the actual slot opening. The effective width is approximately equal to the width of the opening plus one-half the thickness of the two slot edges. (3) Splashing around the sampler may cause a small portion

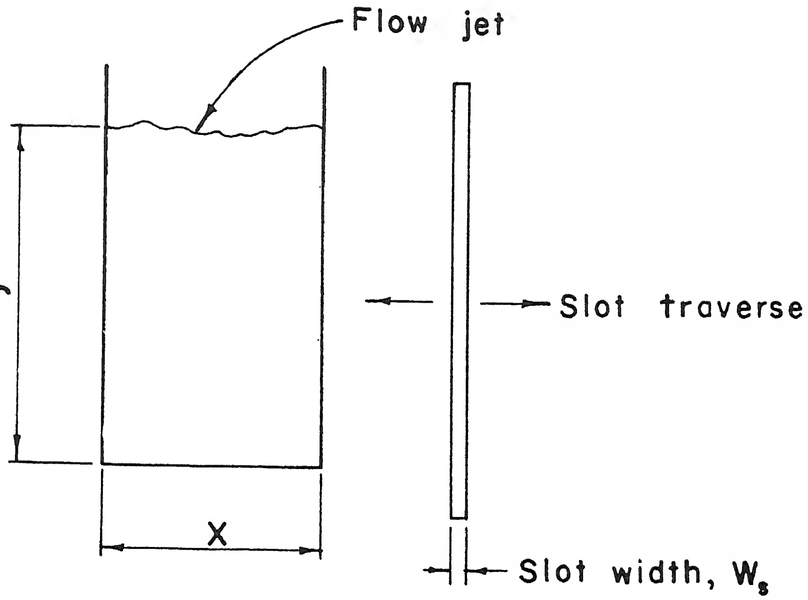


FIGURE 2.—Schematic of sampler operation.

of the liquid to be sampled twice. (4) The sampling rate will be less at high sampler travel speeds. Presumably, this would have little effect at sampler speeds less than 15 or 20 feet per minute.

Results of steady-flow calibration tests on the sampler, mounted on a 1-foot Parshall flume, with an effective slot width of 0.214 inch are given in figure 3. The sampling rate varied from about 0.236 to 0.17 percent of the flow rate at flows ranging from 0.07 to 13.7 c.f.s. per foot of flume width. The mean sampling error, also shown in figure 3, is based on the computed sampling rate (SR) of 0.245 percent. The relatively high sampling error for nearly all flow rates is not alarming since the sampler is not intended as a flow-measuring device.

More important for sediment sampling is the change in sampling rate as the flow rate increases. While there is a significant change in the sampling rate at low flows, between 0.07 and 1.0 c.f.s., the rate of change is small and relatively constant at higher flows. The relationship between sampling rate and flow per foot of flume width is essentially linear at flows between 1 and 14 c.f.s. Presumably, the lower sampling rate at higher discharges is due to increasing head loss through the slot at greater depths and velocities. This suggests that a more uniform sampling rate might be obtained by a tapered slot, slightly wider at the top.

It is readily apparent that a sampling rate from 0.17 to 0.24 percent is much too high for most field situations. For example, 2

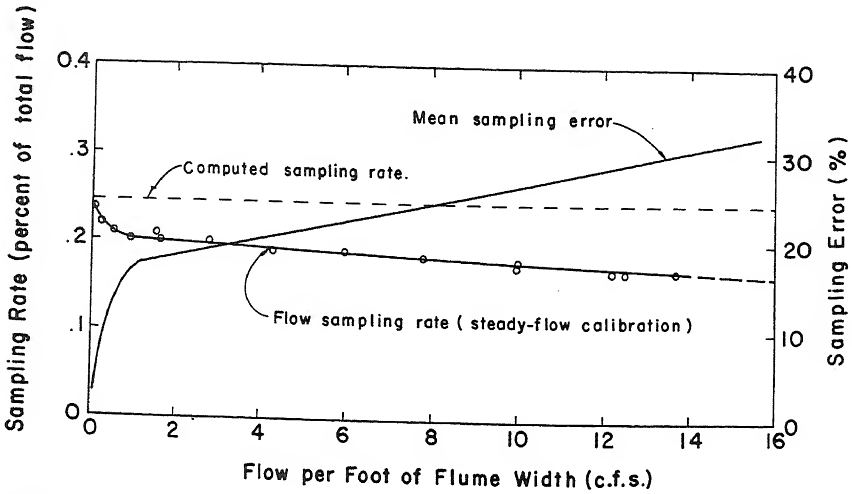


FIGURE 3.—Relationship between sampling rate and flume discharge, steady-flow calibration.

inches of runoff from a 5-acre watershed sampled at a mean rate of 0.2 percent would provide a sample in excess of 72 cu. ft. Vertical space for large tanks is usually not available in the field without excessive excavation. Furthermore, a much smaller sample of the tank sample is required for laboratory analyses.

To reduce the sample size to manageable proportions, a sample splitter was installed on the top of the sample storage tank (fig. 4). It consists of a series of elevated slots with ½-inch openings. As the traversing sampler outflow spout passes over the slots, a portion of the outflow enters the tank through the slots. The lateral spacing of the slots allows only 14.3 percent of the flow volume from the spout to be retained, even though flow into the tank is continuous during each pass of the sampler.

Steady-flow calibration data for the traversing sampler with splitter are given in figure. 5. The relationship between flow and sampling rate is almost as good as for the traversing slot alone (fig. 3), indicating acceptable performance of the sample splitter. The point scatter is slightly greater in figure 5, but the slopes of the sampling rate curves are similar with and without the splitter. The sampling error curve (fig. 5) is based on a computed sampling rate of 0.035 percent, computed as follows:

Traversing sampler computed sampling rate (SR)$=$0.245%

$$0.245\% \times 0.143 = 0.035\%.$$

Other possibilities exist for reducing the volume of sample extracted. These include a narrower slot and a longer sampler pause period on each side of the flume. Alteration of the slot width would require additional tests to establish a new sampling rate and to

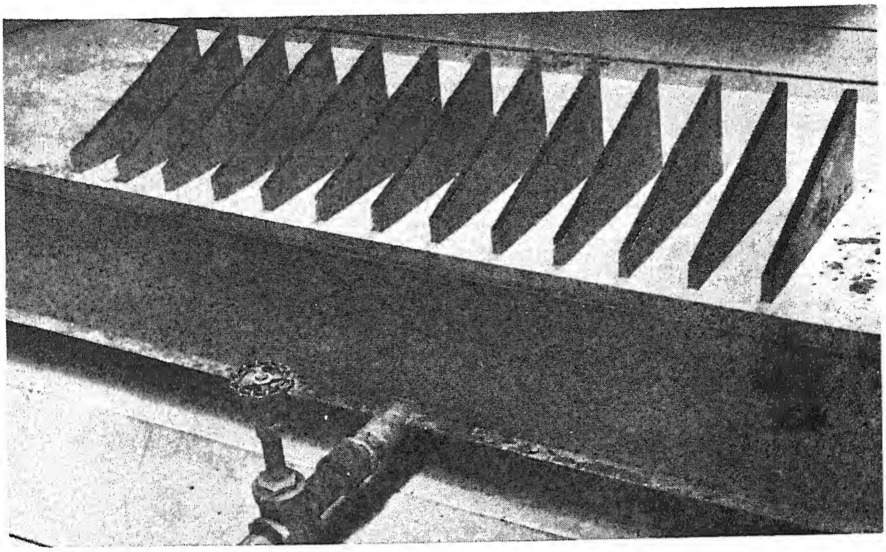


FIGURE 4.—Sample splitter and storage tank. The splitter consists of ½-inch-wide slots.

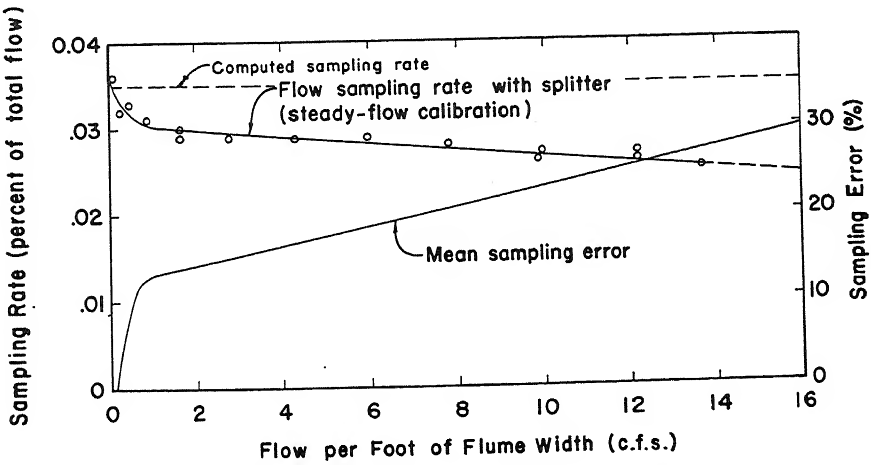


FIGURE 5.—Relationship between sampling rate and flume discharge with sample splitter, steady-flow calibration.

insure proper sampler performance. Furthermore, if the slot width were reduced appreciably, the sampling rate for larger sediment particles, sand size and larger, might become erratic.

The sampler pause period could easily be increased by installing time-delay switches in the electrical circuit. The length of the pause could depend on the rate of change in runoff. For large drainage areas, pauses of 2 to 4 minutes between each sampler pass might

be allowable. For smaller areas where runoff rates change rapidly, almost continuous sampling may be required to provide a representative sample.

SEDIMENT SAMPLING RATE

The sampling rate for sediment being transported in the flow may not always be the same as that for the water. Due to inertia, large, heavy sediment particles, sand sizes and greater, may not follow the curved flow lines as the water enters into or flows around the sampler slot. Also, both flow velocity and coarse sediment concentration will vary with depth in the flow cross section, and the water sampling rate will be slightly greater at the lower flow velocities near the bottom. Presumably, fine sediment particles such as silt and clay will be evenly distributed in the flow vertical; thus the particles will be sampled at essentially the same rate as the water.

Data from limited steady-flow calibration tests with medium size sand are given in figure. 6. These tests were conducted with the sampler mounted on a 6-inch-wide flume and with sand concentrations in the flow from about 500 to 8,700 p.p.m. Unsorted creek-run sand, from 0.062 mm. to about 1.0 mm., with a median particle size of 0.4 mm., was used.

At flow rates between 0.5 and 6.5 c.f.s. per foot of flume width, the sand sampling rate was approximately the same as the flow sampling rate (fig. 6). While larger sand sizes would probably cause greater variations in the sampling rate, the data indicate acceptable sampler performance for medium-size sands.

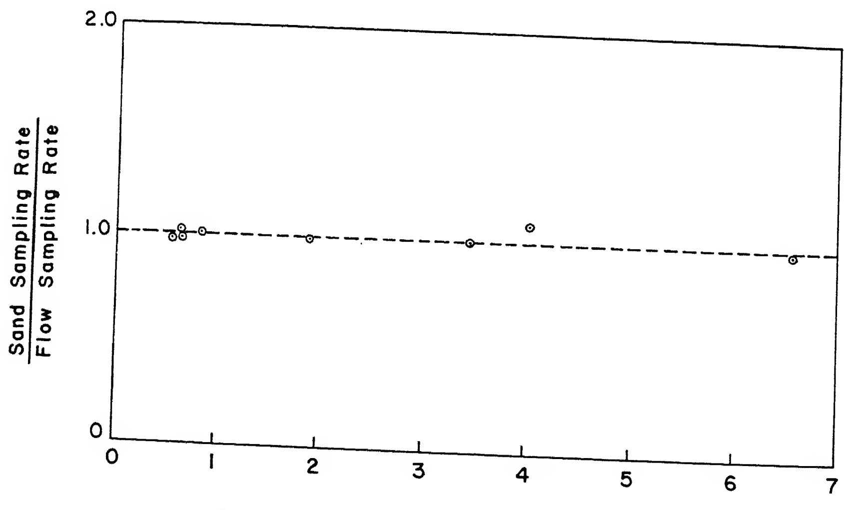


FIGURE 6.—Ratio of sand sampling rate to flow sampling rate at various discharges.

SAMPLER ACCURACY

As previously stated, the sampler was not designed to measure runoff volume. Since the sampling rate decreases as discharge increases (figs. 3 and 5), appreciable error would result if the sample volume, extracted during a given runoff event, and a fixed sampling rate were used to compute the total volume of runoff.

The varying flow sampling rate does not prohibit use of the sampler for determining the mean sediment concentration of runoff. Parsons (*6*), in a report on his work with the Coshocton-type runoff sampler, showed that the mean sediment concentration error for a "generalized" storm hydrograph was relatively small, even though the flow sampling error exceeded 50 percent at some discharges during the runoff event.

Several actual storm hydrographs for a 3.88-acre north Mississippi watershed were used to compute the approximate error in sediment concentration of the sample extracted by the traversing-slot sampler. The storms were chosen to represent a varity of runoff patterns, ranging from a storm with a rapid rise, high peak, and short duration to one with a slow rise, a low prolonged peak, and long duration. Sediment concentration data from a nearby ¼-acre, bare, cultivated plot were used to establish the watershed sediment concentration curves. Peak concentrations were as high as 80,000 p.p.m. for some of these storms.

The mean sediment concentrations for the selected storms were determined by subdividing the total runoff into flow ranges as illustrated in the table. Volume and mean sediment concentration of runoff occurring in each flow range were determined from the runoff hydrograph and the sediment concentration curve. The mean sediment concentration for the storm was then determined by weighting the concentration and flow volume in the various flow ranges.

The sample volume for these storms was determined by multiplying the appropriate sampling rate for each flow range by the runoff volume in the range. Assuming the sampler to extract equal proportions of flow and sediment, the sample concentration was determined by weighing the concentration and sample volume in each flow range.

Errors in the sediment concentration of the sample were less than 5 percent for all of the selected storm events (fig. 7). Since the sampling rate decreases as flow rate increases, the largest sampling error would occur during short-duration, high-peak storms with rapidly changing flow rates. Sample concentration errors for the group of selected storms bear this out. Storms with prolonged peak discharges where most of the total runoff occurs at or near the same flow rate would be sampled most accurately.

Runoff and sample proportions by flow ranges for a selected runoff event with a peak discharge of 16 c.f.s.

q/q_{peak}	Q	Sediment concen-tration	Sampling rate	$Q\times$ concen-tration	Sample volume	Sample volume $\times$ concen-tration
	Cu. ft.	*P.p.m.*$\times 10^{-6}$	*Percent*		*Cu. ft.*	
0 -0.1	4,274	0.0123	0.210	52.57	8.97	0.110
0.1- .2	1,274	.0550	.199	70.07	2.54	.140
.2- .3	987	.0684	.195	67.51	1.92	.131
.3- .4	461	.0738	.191	34.02	.88	.065
.4- .5	673	.0771	.187	51.89	1.26	.097
.5- .6	1,044	.0804	.183	83.94	1.91	.154
.6- .7	1,278	.0819	.179	104.67	2.29	.188
.7- .8	1,479	.0864	.175	127.78	2.59	.219
.8- .9	2,502	.0847	.171	211.92	4.28	.363
.9-1.0	3,726	.0840	.167	312.98	6.22	.522
Total	17,698	——	——	1,117.35	32.86	1.989

Mean sediment concentration of Q: $\frac{1{,}117.35}{17{,}698}=0.0631.$

Sample sediment concentration: $\frac{1.989}{32.86}=0.0605.$

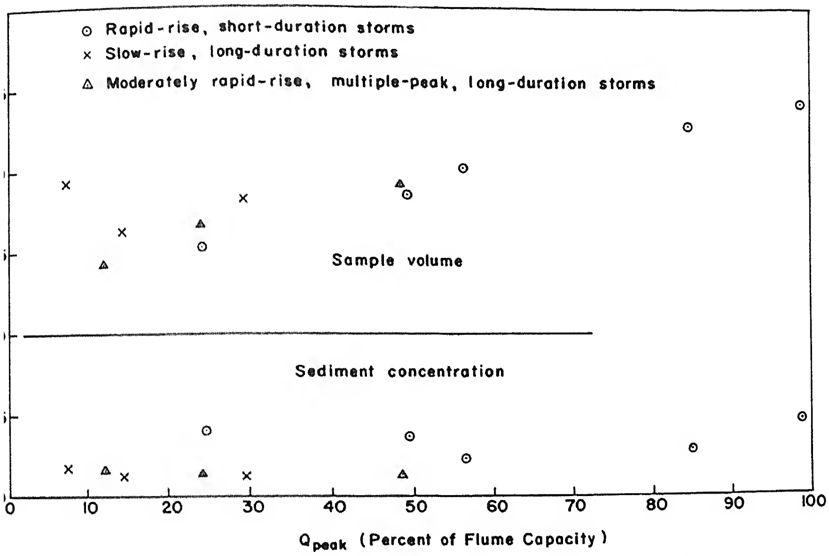
Sample sediment concentration error (percent):
$100-(\frac{0.0605}{0.0631}\times 100)=4.1.$

Although they are not a pertinent part of this study, runoff sampling errors, or errors in the volume of sample extracted, are also shown in figure 7. These errors were determined by comparing the volume of sample actually obtained with the volume that would have been extracted if the sampler had sampled at the computed sampling rate. If computed from the sample volume, errors in total runoff would be of similar proportions.

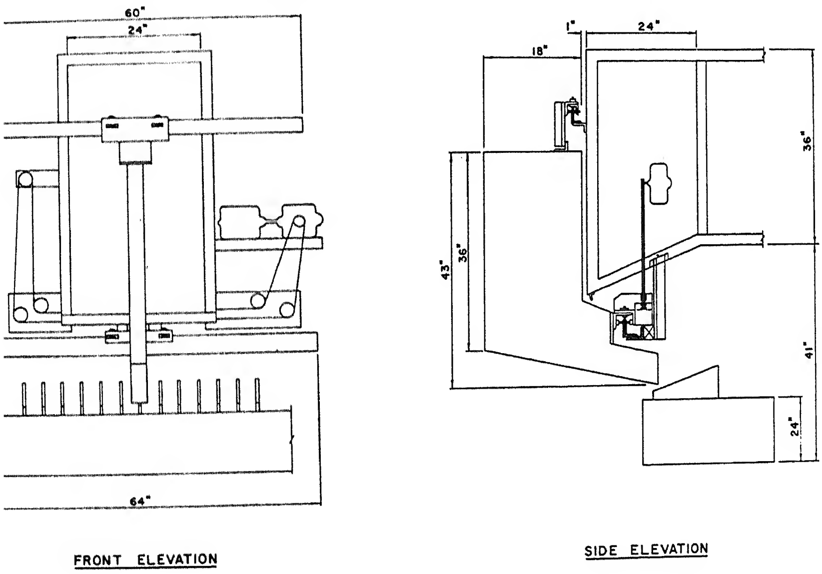
CONSTRUCTION AND INSTALLATION

Horizontal and vertical space requirements for the sampler mounted on a 2-foot Parshall flume are given in figure 8. Slot dimensions and spacing for the sample splitter are given in figure. 9. Drawings showing construction details for the traversing slot and the chain drive mechanism are available at the USDA Sedimentation Laboratory, Oxford, Miss.

The sampler was fabricated from 3/16-inch hard alloy aluminum plate and aluminum angles. The only critical dimensions are the slot width and the width and (bevel) taper of the front edge of



JRE 7.—Sampling error for a group of selected storms as related to peak storm discharge in a 1-foot Parshall flume.



URE 8.—Space required for the traversing-slot sampler mounted on a 2-foot Parshall flume.

: aluminum plates forming the slot. Minor deviations from the t dimensions shown would change the sampling rate significantly.

Good machine-shop practices are required in the fabrication of : sampler. All joints and connections were made with screws or lts. A sealing compound was used at all joints to make the sampler

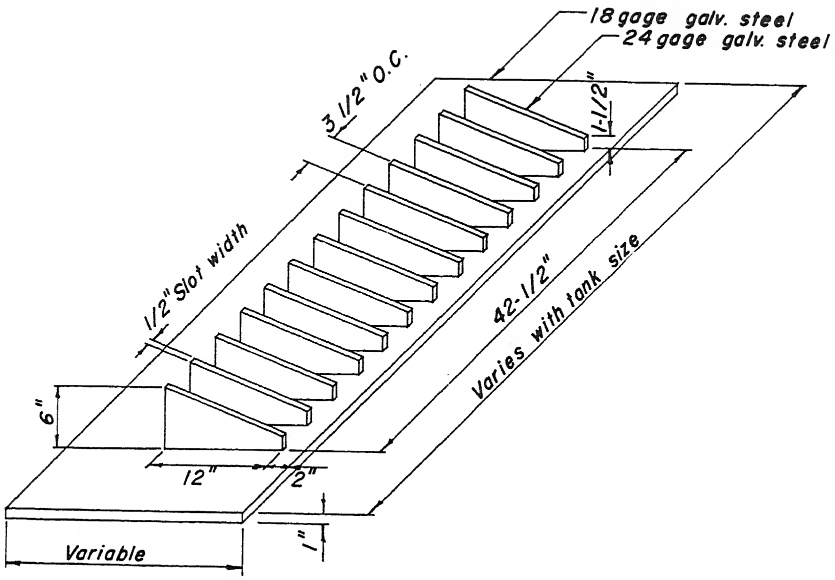


FIGURE 9.—Tank top sample splitter.

watertight. The electric motor, gear speed reducer, roller chain, sprockets, and sealed ball bearings are readily available commercially.

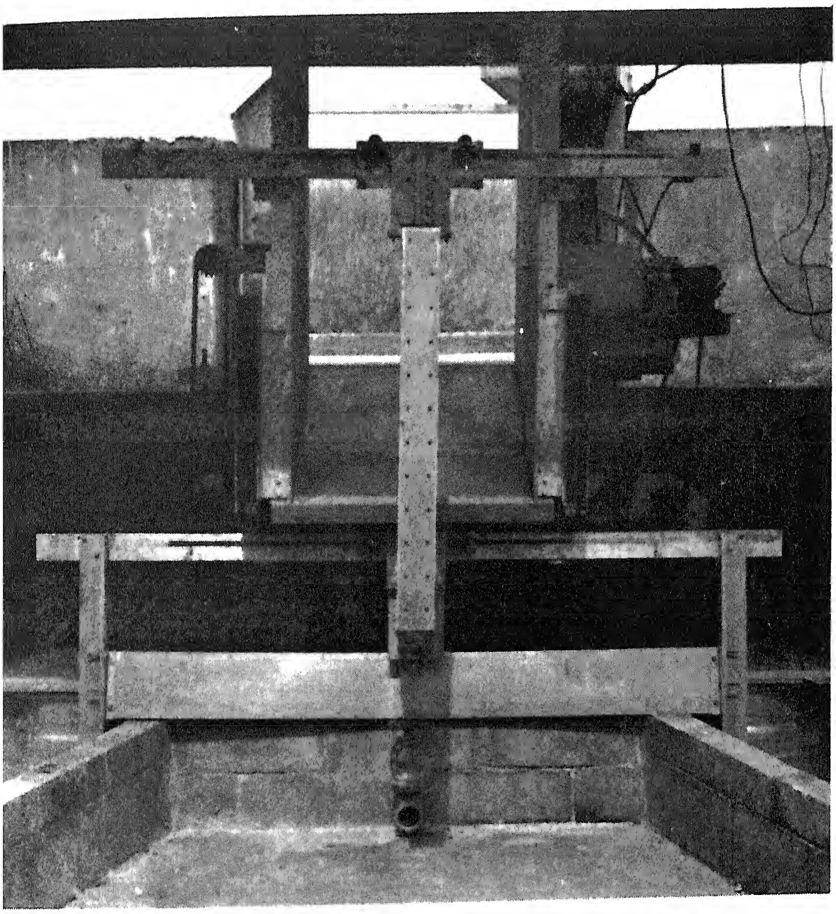
Vertical head requirements sometimes prohibit the use of samplers in the field, particularly on flat slopes. Head requirements for the traversing-slot sampler are fixed (fig. 8), but some leadway is provided in the selection of the sample storage tank. The size of the storage tank depends on the size of the drainage area and the maximum runoff event expected. The dimensions given in figure 8 are the minimum required for a storage tank depth of 1 foot.

The sample splitter was fabricated from 18-gage (top) and 24-gage (elevated slots) galvanized sheet metal (fig. 9). Openings were cut in the top, and the elevated slots were placed in position and soldered. For large tops, small angle-iron stiffeners are needed. Good machine-shop practices are required in the fabrication of the slots to obtain exact slot dimensions.

FIELD PERFORMANCE

For field tests the sampler was mounted on a 2-foot Parshall flume and installed on a 1.6-acre cultivated (corn) watershed (fig. 10). A shelter was provided to protect the motor, batteries, and chain drive. Electric power was available at the site, so a trickle charger was installed to keep the batteries fully charged.

Mechanically, the sampler has performed satisfactorily with virtually no downtime. Maintenance requirements have been minimal. Anticipated problems with trash collecting on the sampler were



GURE 10.—Field installation. Sampler mounted on a 2-foot Parshall flume below a 1.6-acre watershed.

iminated by mounting fiber brushes on each side of the flume so .at the slot was brushed lightly at the beginning and end of each ıss through the flow jet. Excessive splash from the jet falling on ıe concrete floor below the sampler was controlled by erecting a nall dike, which created an 8-inch-deep plunge pool beneath the :t.

Based on the total storm runoff volumes, determined from the ume stage-discharge relationship, the flow sampling rate varied ›nsiderably between storms. Generally, the error in the volume f the sample, based on the computed sampling rate, ranged between and 36 percent for a variety of storms with runoff volumes rangıg from 0.14 to 2.3 inches, and peak discharges ranging from 0.7 › 5.6 c.f.s. Data are not yet available to evaluate the field performnce of the sampler for determining the sediment concentration f runoff.

ACKNOWLEDGMENTS

The assistance of W. A. Champion, engineering technician, the late J. C. Hartsfield, mechanical engineering technician, and R. N. White, former machinist helper at the USDA Sedimentation Laboratory, in the construction and testing of the sampler is gratefully acknowledged.

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